



Modelling a heterogeneous Upper Cretaceous reservoir through seismic reservoir characterization and Geo Cellular Model: A case study from Cauvery Basin

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Abstract

Unravelling the heterogeneities and compartmentalization within a hydrocarbon reservoir and incorporation of these into the geo-cellular model is a vital factor for the development strategy of any field. The SD-20 sand belong to the Upper Cretaceous Nannilam formation and is a major oil and gas producer of the field in the study in Cauvery Basin. The existing model for this reservoir envisages it as a single sand body. However, this model fails to explain the variations within the fluid distribution, pressure and production behaviors and abrupt facies changes in the wells.

The present study has brought out several heterogeneities within this reservoir and addresses all these issues by bring out the configuration of three sand lobes in place one through integrated seismic, reservoir pressure and production data analysis. The study also brings out a revised depositional model as discrete sand lobes deposited by slope fans and debris flows. Vp/Vs slices are suggesting that the absence of reservoir facies is found to be in the inter-lobe areas. The structure and sand maps have been prepared for the mapped bodies.

A Geo-Cellular model (GCM) was constructed with a resolution of 20mx20m (lateral) x ~5m (vertical) by incorporating well data, mapped surfaces, faults and Vp/Vs volume. 3D facies volume has been prepared by upscaled well data and populated using Vp/Vs volume. The porosity model was generated by geostatistical method by incorporating the well data. The water saturation was modelled by Cuddy-modified Lalanne method. The robustness of the modelling is validated by the good match of the

properties predicted and the well data. The final pay sand maps such as average porosity, iso-saturation and iso-pay maps for the three lobes have been prepared from the GCM. Based on the static model results, three development areas are identified. The present study is highly useful for further simulation, field development planning and to understand the facies variation.

Introduction

Cauvery basin is one of the prolific petroliferous basins of India located along the southeast coast of India (Fig. 1). It is a pericratonic rift basin evolved during Late Jurassic break up of Gondwanaland and developed into a passive margin setup by the end of Cretaceous (Rangaraju et al., 1993). The basin is evolved as several horsts and graben due to the interaction cross-trends and drifting. Early Cretaceous Synrift Andimadam shales are effective mature source rocks in this basin. Commercial hydrocarbon is established throughout geological column right from Proterozoic fractured basement to Oligocene Neravy sands.

Field X (Fig. 1) was one of the earliest discoveries of Cauvery basin, located at the junction of Nagapattinam and Tranquebar sub-basins. The field is producing commercial oil and gas volumes from both Upper Cretaceous Nannilam and Paleocene-Eocene Kamalapuram sands. The present study focuses on the reservoir characterization and preparation of Geocellular model of a major pay sand (SD-20) which is highly heterogeneous and hosts 80% of field's reserves. The study would be helpful for further development of the reservoir.



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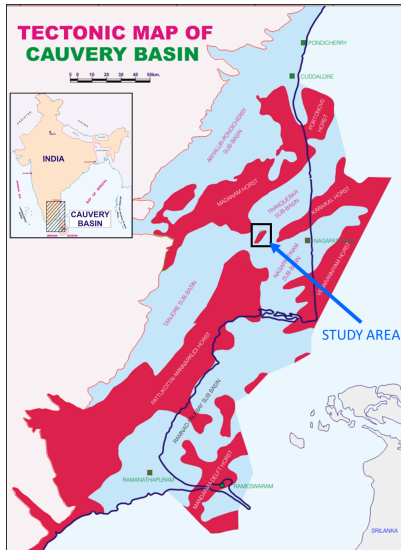


Figure 1: Tectonic map of Cauvery Basin showing study area (rectangle).

The SD-20 belongs to upper part of Nannilam formation and it has been producing oil and gas from more than last 20 years and presently is in mature stage with high water cuts at drilled wells. The existing reservoir model shows the NNE-SSW trending linear single body having structural high axis in the central part rising towards south (Fig. 2). It is an oil and gas reservoir with a ~20m thick Gas cap and 9m thin oil rim with bottom water support. The thickness of the sand varies from 10m to 45m and is having an average effective porosity of 24% and 70-250md permeability. The wells shown in the Fig.2 from A to J (in alphabetical order) are hydrocarbon producers while wells Q & R are below oil water contact. Though the well L lies structurally higher position, it lies in the different fault block and is water bearing. The SD-20 is not present in the wells M, N and P, which are lying on the structurally high (with respect to the basement and deeper formations). Surprisingly in the well K, lying in the middle part of body, the sand is not developed. In the latest well O, towards south, a new gas sand was reported which is considered as equivalent to SD-20, but in view of fluid contacts and pressure differences, it was considered as different body.

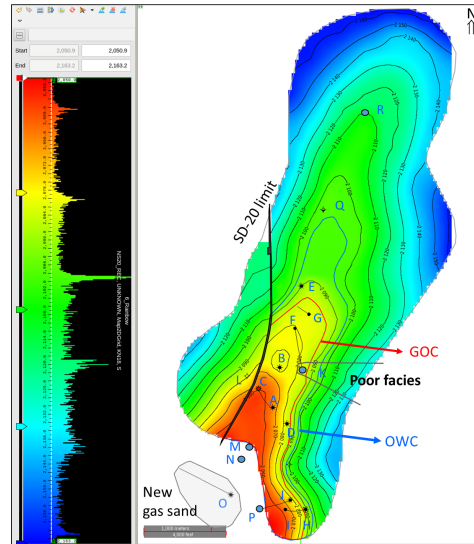


Figure 2: Existing structural map of SD-20 showing a NNE-SSW trending single body. Towards south a new gas sand equivalent to SD-20 was discovered at well O.

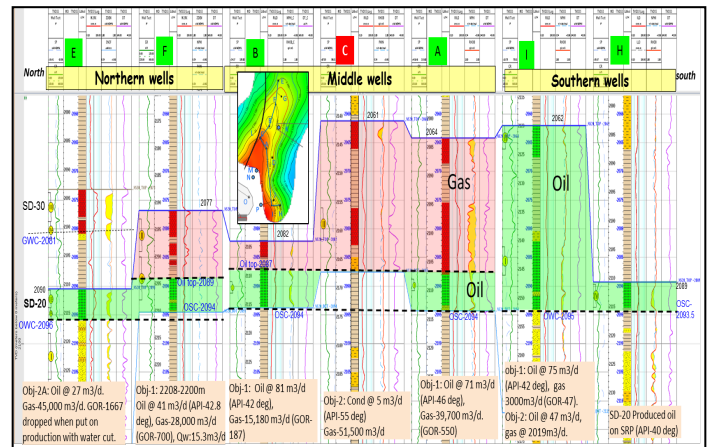


Figure 3: N-S log profile along wells showing heterogeneous fluid juxtaposition in middle and southern wells.

Reservoir Characterization

A close look on the well logs in N-S profile gives a glimpse on the heterogeneity of the SD-20 (Fig. 3). As the southern wells (H, I, J) are producing oil even from upper part of SD-20, which are having gas from the wells at middle part (A, B, C & D). This suggest

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that the middle and southern part of the sand is not in communication. Though the fluid contacts are close in the wells from middle and northern part, the movement of OWC is not uniform. In the last well G in the northern part, OWC was intact (OSC-2094m) while in the well D (drilled 7 years prior to well G), the OWC is moved up to 2088m. Variation in the reservoir pressure behaviour of wells also suggest that this body might be comprising three different pools (Fig. 4).

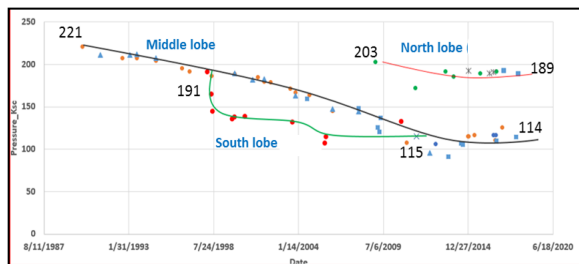


Figure 4: Reservoir pressures from wells in SD-20.

A detailed seismic mapping reveals that SD-20 is consisting of laterally distributed three different sand lobes possibly deposited in same age. The southern and middle part of this sand shows a different nature from low amplitude (Well J) to high amplitude (well A & B) packages (Fig 5). Seismic study also reveals that a fault exists between these two bodies. The northern and middle parts have similar seismic character, but the reflectors corresponding to different with a slight overlap at well E. Thus, these bodies have been mapped as three bodies viz., SD-2 (middle part), SD-3 (southern part) and SD-9 (northern part).

The cut due to erosion at the end of K/T led to the development of canyon features at the west and southern parts of field X (Fig. 6). Thus, the western continuation of sand bodies are eroded (Fig. 6b). The new local sand observed at well O was mapped as SD-4 (Fig. 6c). The absence of sand at M, N and P can be attributed to the presence of paleo high at these wells.

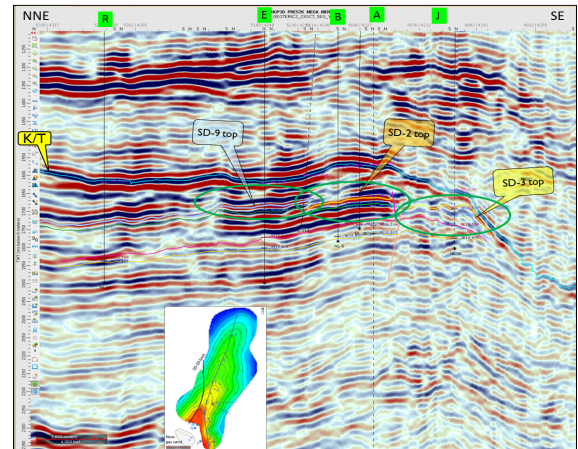


Figure 5: The NNE-SSE RC seismic line showing heterogeneity nature of SD-20 (mapped as SD-2, SD-3 & SD-9). Notice the cut at K/T level leads to wedge-out of Nannilam sands towards southeast.

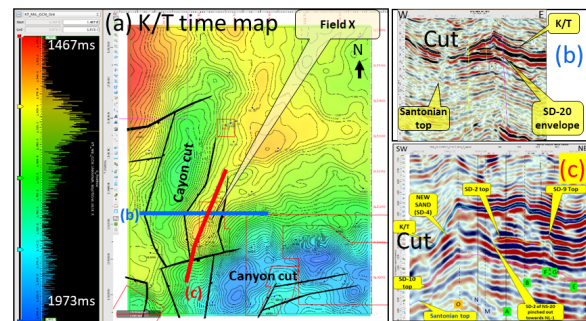
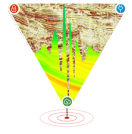


Figure 6: (a) Time map of K/T showing the presence of cuts towards south and west of field X. These cuts are also demonstrated in E-W (b) and N-S (c) seismic sections. Due to these cuts the sands towards west of field X are eroded.

The seismic mapping of the mapped sand bodies has brought out the structural configuration and disposition (Fig. 7a). The RMS amplitude attribute broadly showing the several bodies aligned in NNE-SSE orientation (Fig. 7b). Pre-stack inversion has been carried out as the facies discrimination is feasible in Vp/Vs domain (Fig. 7c). The Vp/Vs slice in the window from the SD-20 envelope top to 25ms below (Fig. 7d) is clearly displaying the three separate sand bodies possibly having input from west. The wells K and M, N are lying the in the inter-lobe area which shown absence/ poor facies.



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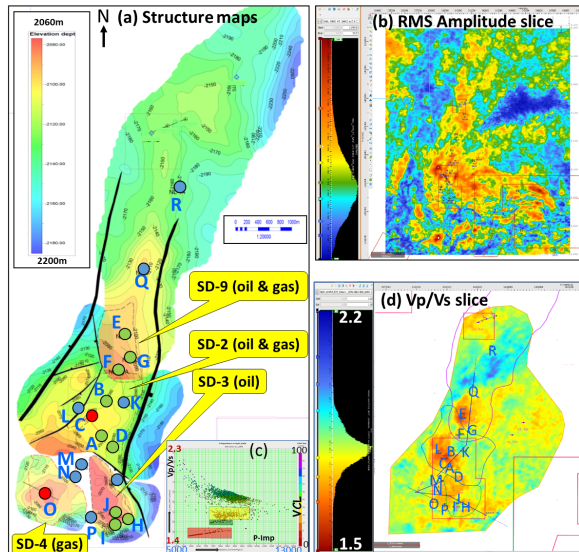


Figure 7: (a) Structure maps of sand bodies of SD-20. (b) RMS attribute slice from K/T to Santonian top. (c) Cross-plot of P-Impedance vs Vp/Vs coloured by Vclay. (d) Vp/Vs slice in the (window from SD-20 envelope top to 25ms below). Note wells K, M, N are in the inter-lobe areas with high Vp/Vs values.

Depositional Model

It is essential to incorporate the proper depositional model into the Geocellular models as each model has specific variations in reservoir distribution. As the pre-existing model envisages a NNE-SSW trending single channel body, but heterogeneities can be seen such as sudden absence of facies at wells K, M and N though they are lying the axial part of channel (Fig. 2).

The available sedimentological reports suggest that Nannilam sands are deposited in outer shelf to upper bathyal environment in this area. The available core data (Table-1) in the study area suggest that these sands are mostly immature, poorly sorted arkosic wacke with high feldspar and clay matrix suggesting the short distance transport from nearby provenance. Presence of planktonic foram and horizontal burrows suggest the deeper bathymetry. The presence of angular rip up clasts of shale floating in sand indicate partially fluidized rheology, which is characteristic of debris flows. Since matrix was more with plastic rheology, they are derived by gravity driven debris

flow mechanism which deposit as slope fans of restricted areal extent, rather than totally fluidized turbidites which deposit extensive channel or sheet sands.

Well	Depth m MD	Sedimentary characteristics.	Mode of deposition
A	2084-2092	Fine to medium grained, calc arenite, foram tests, chloritic matrix.	Slumps/ debris flows
B	2107.5-2114	Arkosic wacke, presence of angular rip up clasts of shale in sand.	Resedimented deposit/ Debris flows
H	2112-2116	Fine to medium grained, arkosic wacke, horizontal burrows, foram tests, current bedding	Resedimented deposit/ Debris flows

Table-1: Sedimentological description of available cores in the study area (Mani, 2000).

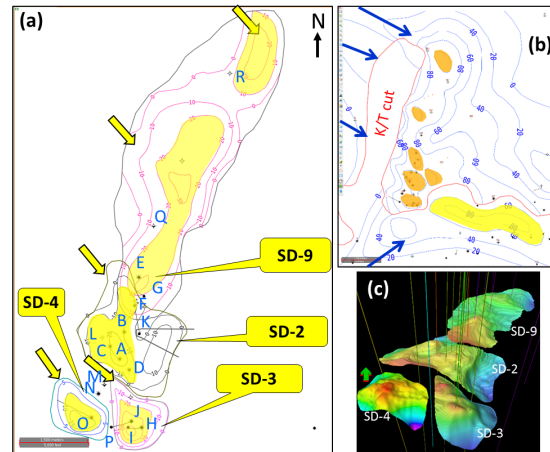


Figure 8: (a) Sand isolith maps of four mapped sands. (b) Envisaged depositional model of Nannilam sands. (c) Modelled sand top surfaces in 3D view.

The sand isolith maps of each sand body and total Nannilam formation are prepared from well data and refined with seismic attribute also suggest that these sands have been deposited as isolated slope fans derived from western Kumbakonam high (Fig. 8).



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Static Geo-Cellular Model

A 3D structural model was prepared in the window from K/T to Santonian top by pillar grid method, where in the mapped sand bodies are incorporated as zones. Total 578 layers have been prepared by keeping a horizontal resolution of 20x20m and a vertical resolution of ~0.5m in sand zones in the 3D Grid (Fig. 9). The regions were defined as per fault blocks and sand bodies.

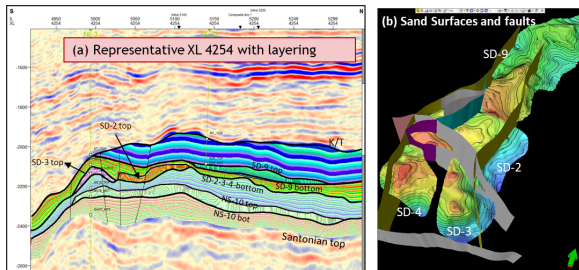


Figure 9: (A) The N-S seismic section shows the layering adopted for GCM. (b) The mapped sand surfaces and faults incorporated in the model in 3D perspective.

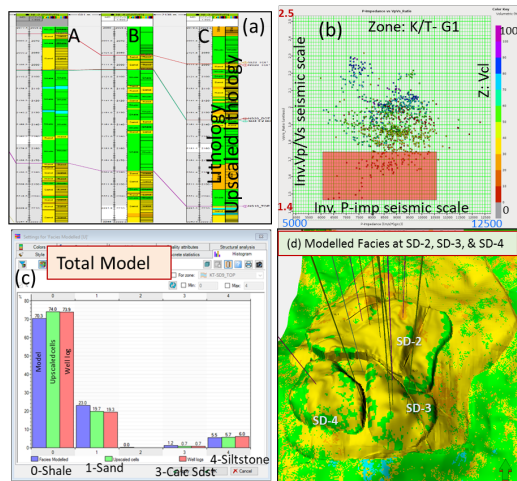


Figure 10: Snapshots of Facies Modelling. (a) Well lithology & upscaled lithology in model at 3 wells. (b) Cross-plot of P-Impedance vs Vp/Vs coloured by Vclay in seismic scale. (c) Comparison of facies histogram of modelled and well lithologies. (d) Model showing facies on different zones in 3D.

The well lithology was upscaled in the 3D model and geostatistically populated in the entire model using the Vp/Vs volume as secondary trend (Fig. 10). A very good match among well lithology, up-scaled lithology and modelled lithology is obtained in all the zones (Fig. 10c).

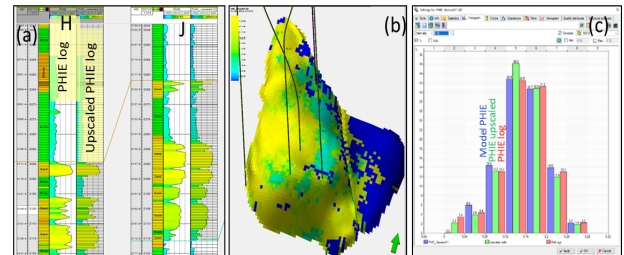


Figure 11: Snapshots of Effective porosity modelling. (a) Comparison of well and upscaled effective porosity (PHIE) logs. (b) Modelled PHE volume showing at SD-3. (c) Comparison of modelled and well PHIE histograms.

Effective porosity logs in the wells were up scaled to model grid (Fig. 11a). The upscaled logs were geostatistically populated in the entire 3D grid (Fig. 11b). The histograms for modelled porosity show a good match with the drilled well porosity is obtained in the final porosity model (Fig. 11c).

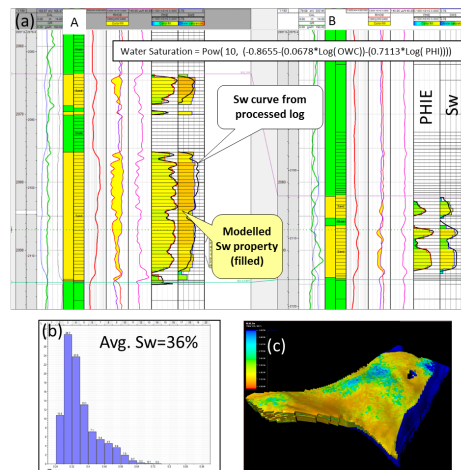
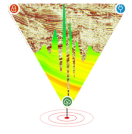


Figure 12: (a) comparison of well and modelled water saturation (Sw) curves. (b) Average Sw in the block SD-2. (C) Sw model in 3D view.



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After upscaling Water Saturation (Sw) logs in model grid, 3D Sw modelling was carried out using Cuddy - modified Lalanne Method (Lalanne et al., 2014) (Fig. 12a) for sand zones. Good match is obtained at wells (Fig. 12b) with the modelled Sw. After modelling, average porosity and water saturation maps are generated where the high and low porous and hydrocarbon saturation zones can be assessed (Fig. 13).

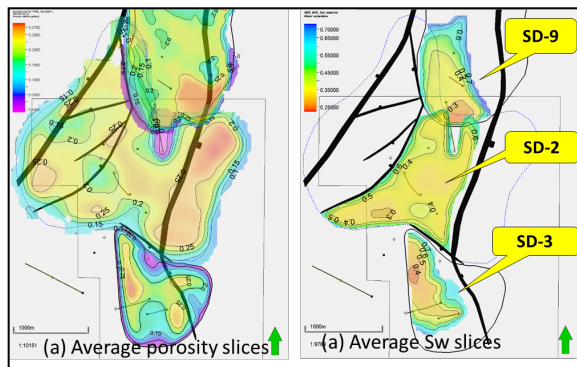


Figure 13: (a) Average porosity maps and (b) Average water saturation maps of the three sand bodies (SD-2, 3 and 9).

Utilizing the petrophysical cut-offs, net pay maps generated for gas and oil zones for each sand (Fig. 14). The oil pay map of SD-3 shows that the northern part of SD-3 is unexploited (Fig. 14a) and this area needs to be developed (location shown as D2). The oil pay map of SD-2 (Fig. 14b) also shows the western part of well A (location shown as D1) and the area between wells A and B can be helpful to exploit the remaining volumes. However, these needs to be further substantiated by reservoir simulation studies. The prepared model is highly useful for further reservoir simulation study, volumetric assessment at static model level, checking facies nature and further development plans of the field.

Conclusions

The present study has revised the existing single reservoir model and brought out a three different sand lobes which are not in communication. The heterogeneities within the existing single body was effectively identified by well logs, fluid juxtaposition, seismic and reservoir pressure studies. The variation in reservoir facies is properly addressed

by Vp/Vs results from Pre-stack inversion. A new depositional model in terms of discrete slope fans is envisaged in place of existing channel feature for upper Nannilam sands. The static GCM is helpful for future development plans in the field and further reservoir simulation studies. The study has also brought out three future development areas in SD-2 & SD-3.

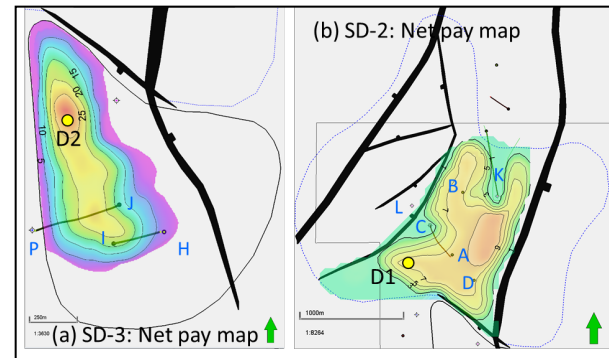


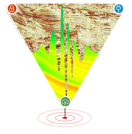
Figure 14: Net pay maps of (a) SD-3 and (b) SD-2. Also shown the suggested development locations D1 & D2.

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